Use of a microsphere probe for pressure field measurements in the megahertz frequency range[a]

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A procedure has been developed that may be used to measure the finestructure of acoustic fields at frequencies up to 10 MHz. It consists basically of locating a microsphere in the pressure field at the point of interest and measuring the amplitude of the scattered waves. Details of the system are discussed, and some examples of experimental data presented.

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A number of procedures have been developed to study the finestructure of acoustic fields in the megahertz frequency range.[1] The schlieren technique provides an overview of the fields.[2] Field patterns of the nearfield have been recorded on photographic emulsion by Dehn.[3] Cholesteric liquid crystals provide a means to visualize and map the field on a plane by plane basis.[4] Small thermoelectric probes have been developed using both thermocouples and thermistors that yield the intensity of the acoustic beam on a point by point basis.[5,6] The above systems, with the exception of the schlieren technique, respond to the time average of the beam intensity or pressure, whereas piezoelectric transducers respond as a function of time to the instantaneous pressure averaged over the sensitive element. Piezoelectric transducers with sensitive dimensions of a millimeter, or less, have been constructed[7]; Romanenko[8] fabricated a spherical barium titanate transducer with a diameter of 0.2 mm. The schlieren technique does not involve time averaging and is capable of recording the propagation of short pulses of ultrasound and may be used to obtain a quick qualitative picture of the entire sound field. Research is now in progress to develop the schlieren technique for quantitative measurements of sound field amplitude.[9] At this stage it is not known how precise schlieren measurements of sound amplitude can be. Also, in contrast to the technique described here, quantitative schlieren measurements of sound amplitude will require extensive signal processing due to the integrated optic effect. However, the schlieren method has the unique advantage of allowing rapid scanning of the sound field. We wish to report here on a procedure we have developed that provides for the quantitative measurement of the fine structure of acoustic fields at frequen-

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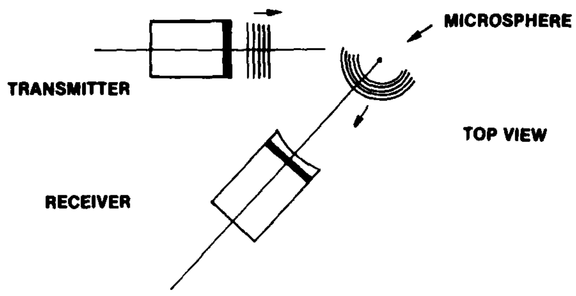

FIG. 1. Microsphere probe pressure measurement. The microsphere is located at the focus of the receiving transducer lens. The microsphere and receiver remain in a fixed position and the transmitter is positioned so that the microsphere is in the location where the pressure field is to be determined.

cies up to 10 MHz and with resolutions of 0.05 mm or better. Basically the method involves placing a sphere, which is small compared with the fine structure of the field, in the field and measuring the pressure amplitude of the scattered sound using a piezoelectric transducer. In our measurements we have used long pulses and obtained essentially continuous-wave results, but the procedure should be useful for transient studies also.

The procedure used is illustrated in Fig. 1. The transmitter emits pulses of the desired frequency, and the microsphere scatters a wave with an intensity proportional to the intensity of the incident wave at that point. The microsphere is located at the focal point of the receiver lens, and the amplitude of the scattered wave is measured by the receiver. In our experimental arrangement the receiver and microsphere are kept in fixed positions, and the transmitting transducer, whose field is being investigated, is positioned so that the microsphere is in the desired pressure-field location.

For the system to accurately indicate the relative pressure at a given position, it is necessary for the microsphere to be small enough for the pressure field to be essentially constant over it, and also the amplitude of the scattered wave should be relatively independent of the scattering angles involved. The microsphere used was a glass shell of 55-μ diameter and 1.6-μ wall thickness. The effective bulk modulus of this microsphere was calculated to be 2.7×10^9 N/m^2. Thus, the microsphere is somewhat stiffer than the surrounding water whose bulk modulus is 2.1×10^9 N/m^2. Therefore, the scattering cross section of the glass bubble will not exhibit the large resonance peak typical of soft scatterers such as air bubbles, and the region of the pressure field sampled by the microsphere is essentially equal to its physical size. In our experimental arrangement, as in Fig. 1, the scattering angles involved change a relatively small amount since the transmitter is always positioned with its axis parallel to a fixed direction, and if $ka \leq 1$, (k is the acoustic wavenumber and a is the sphere radius) then the amplitude of the scattered wave will be practically independent of the scattering angles that occur. (This estimate is based on the scattered intensity patterns for a hard sphere given by Morse and Feshbach.[10]) Figure 2 shows an example of measurements made with the microsphere probe. It shows the pressure along a line through the focal point of the transmitter lens and perpendicular to the transmitter axis. The 0.5-in.-diam transmitter was operating at 5 MHz and had a 1.06-in. focal-length Lucite lens mounted on it. The receiver lens was a Lucite lens of 1.38-in. focal length. The microsphere was a 55-μ-diam glass bubble mounted on a 15-μ-diam nylon filament. The filament was horizontal and perpendicular to the transmitter's axis, and with it in that position the main scattering from it was normal to it. The axis of the receiver was at 60° to the filament's normal, and the scattering from the filament to the receiver was found to be about 35–40 dB below that from the microsphere.

Figure 3 shows some nearfield measurements made with no lens on the transmitter, but otherwise the experimental setup is the same as above, and in Fig. 2. In Fig. 3 are shown the theoretical curves obtained by numerical evaluation of the exact integral solution for the pressure field of a harmonically excited baffled piston.

In both Figs. 2 and 3, the sphere diameter is seen to be small relative to pressure-field variations with position. Also, at 5 MHz, with the radius of the sphere about 28 μ and the pressure wavelength about 300 μ, $ka \simeq 0.5$.

The microspheres used were taken from bulk material sold by Emerson and Cuming, Inc., under the trade name "Microballoons" for use as low density fillers for addition to plastics and other binders. In order to get one sphere for mounting, a small amount of the bulk

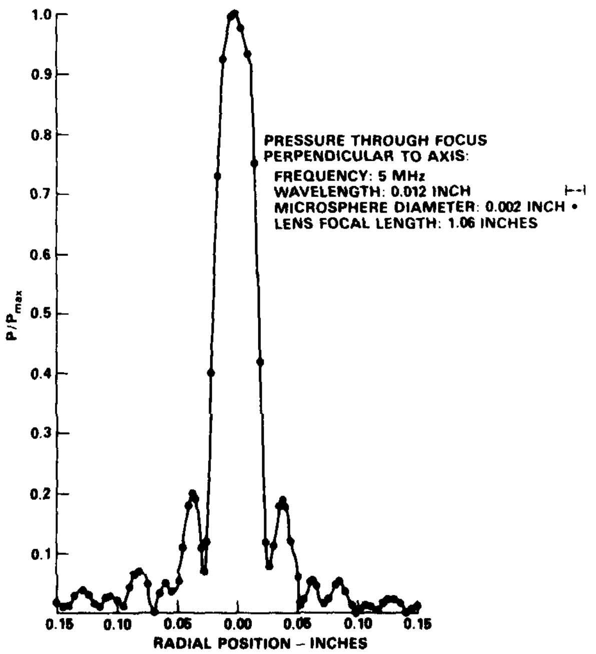

FIG. 2. Pressure amplitude field through focal point of lens mounted on face of transmitter as a function of radial distance from transducer axis. Note that the microsphere diameter is small compared to the finestructure of the acoustic field.

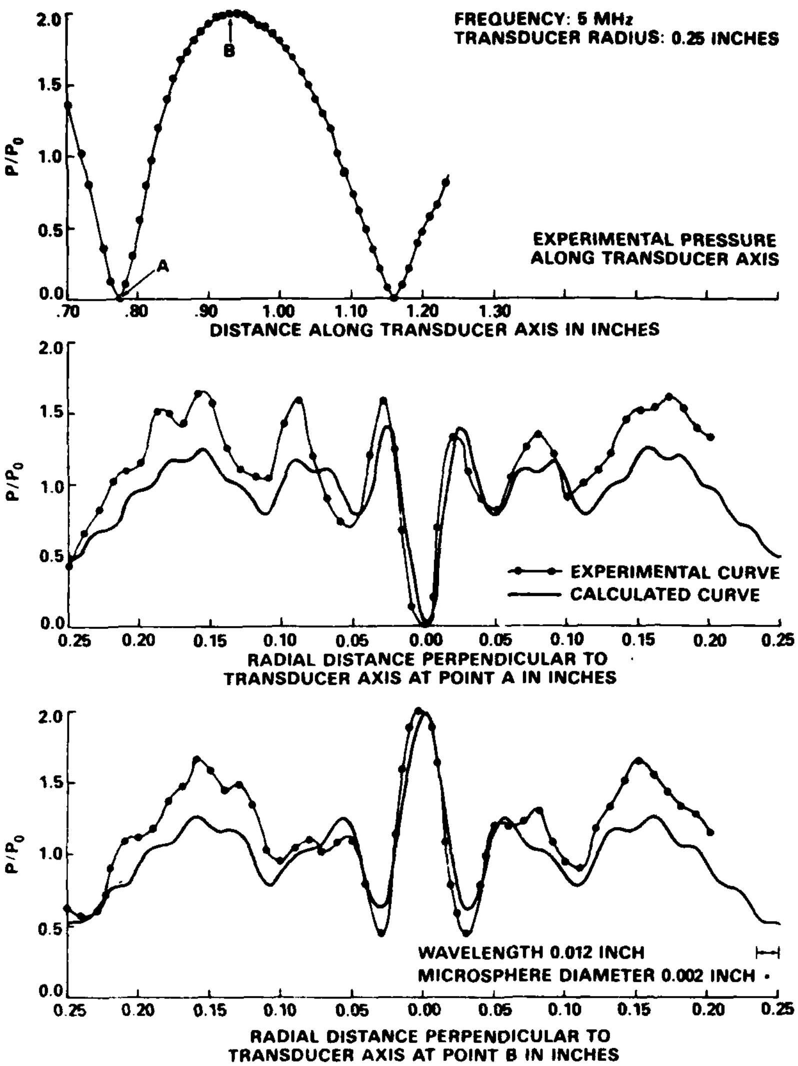

FIG. 3. The top curve shows the experimentally determined pressure in the nearfield along a portion of the transducer axis. The middle curves show the calculated (solid curve) and experimental pressure curves along a line perpendicular to the axis at point A in the top curve, and the lower curves show the same curves along a line perpendicular to point B in the top curve. The size of the microsphere is shown to scale in the lower diagram, and from this it is apparent that the microsphere samples a volume of almost constant pressure.

material was diluted several times with distilled water, then drops of water with the glass bubbles in them were placed on a glass microscope slide. When the drop on the glass slide has almost evaporated, the slide was placed under a microscope (18× magnification), and the spheres separated from each other with a fine needle point. The nylon filament was obtained by separating out a single filament from a nylon fishing line.

The microsphere was mounted on the filament using a clear silicone potting compound, RTV 602, manufactured by General Electric. The procedure for mounting was this: An insulated needle point was brought into contact with the chosen microsphere. The microsphere stuck to the needle, probably due to electrostatic attraction. The nylon filament was positioned, stretched taut and a small amount of the RTV 602 compound was placed on the filament, near its center. The sphere on the needle was then brought into contact with it, where it stuck. Figure 4 shows a mounted microsphere.

The microsphere probe described was designed for use in the 5-10 MHz frequency range, and the specific requirements for sphere size were that the sphere be small enough that the pressure would be essentially constant over its volume, and that it act as a uniform scatterer over the small range of scattering angles involved. The filament to which it was attached should have a small size, an impedance near to that of water, and should be mounted so that the wave scattered by it toward the receiver is negligible compared to that from the microsphere. The cement used to attach the microsphere to the filament should be small enough in quantity and have an impedance near enough to that of water so as to have little effect on the scattered wave. The 55-μ-diam microsphere, the 15-μ-diam nylon filament, and the RTV 602 silicone potting compound worked well for us in plotting lens focal regions and the nearfield of 0.5-in.-diam transducers operating at 5-10 MHz. Smaller spheres and filaments should work at higher frequencies, and at lower frequencies larger diameter spheres and filaments should prove useful.

All measurements reported here were made with pulses that were long enough that transient effects could

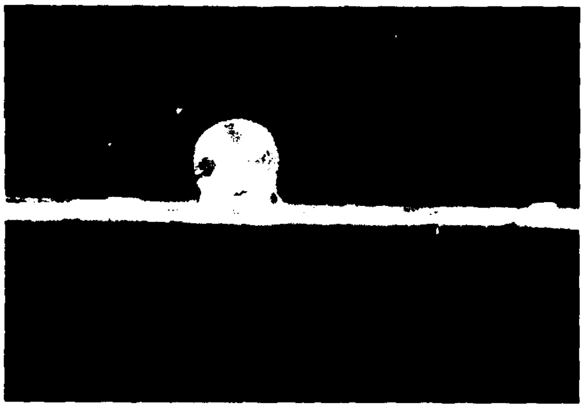

FIG. 4. Microsphere mounted on nylon filament. This microsphere is 85 μ in diameter.

be neglected, and so our results are equivalent to continuous-wave results. Also, all the pressure amplitudes are relative, and no attempt was made to make phase measurements. The system could, however, be calibrated to give absolute pressure amplitudes, and has the potential to be used for phase determinations and the measurement of transient pressures.

[1]Various procedures for ultrasonic pressure field studies are discussed by E. P. Papadakis in "Theoretical and Experimental Methods to Evaluate Ultrasonic Transducers for Inspection and Diagnostic Applications," IEEE Trans. Sonics Ultrason. **SU-26**, 14–27 (1979).

[2]L. R. Dragonette, "Schlieren Visualization of Radiation Caused by Illumination of Plates with Short Acoustical Pulses," J. Acoust. Soc. Am. **51**, 920–935 (1971).

[3]J. T. Dehn, "Interference Patterns in the Near Field of a Circular Piston," J. Acoust. Soc. Am. **32**, 1692–1696 (1960).

[4]B. D. Cook and R. E. Werchan, "Mapping ultrasonic fields with cholesteric liquid crystals," Ultrasonics **9**, 101–102 (1971).

[5]F. Dunn and W. J. Fry, "Precision Calibration of Ultrasonic Fields by Thermoelectric Probes," IRE Trans. Ultrasonic Eng. **UE-5**, 59–65 (1957).

[6]P. E. Woolley, R. J. Barnett, and J. B. Pond, "The use of probes to measure megahertz ultrasonic fields in liquids," Ultrasonics **13**, 68–72 (1975).

[7]J. Saneyoshi, M. Okujima, and M. Ide, "Wide frequency calibrated probe microphones for ultrasound in liquid," Ultrasonics **4**, 64–66 (1966).

[8]E. V. Romanenko, "Miniature Piezoelectric Ultrasonic Receivers," Soviet Phys.-Acoust. **3**, 364–370 (1957).

[9]J. A. Bucaro, L. Flax, H. D. Dardy, and W. E. Moore, "Image Profiles in Schlieren Observations of Acoustic Wave Fronts," J. Acoust. Soc. Am. **60**, 1079–1084 (1976).

[10]P. M. Morse and H. Feshbach, *Methods of Theoretical Physics* (McGraw-Hill, New York, 1953), p. 1485.